DESCRIPTION

COLD DIE STEEL EXCELLENT IN CHARACTERISTIC OF

SUPPRESSING DIMENSIONAL CHANGE

TECHNICAL FIELD

The present invention generally relates to a

tool material, and particularly relates to a cold die

steel preferably used in a die assembly for molding

5   components for a household electrical appliance, a

mobile telephone, an automobile and the like.

BACKGROUND OF THE INVENTION

Conventionally, JIS SKD11 has been in heavy

usage for a cold die steel, but some attempts have been

10   made to modify the SKD11 in order to improve

machinability, toughness and hardness after secondary

hardening. For instance, there proposed are (1) a cold

die steel referred to 10%Cr SKD (see JP-A-11-279704)

which has improved machinability and toughness, in

15   which amounts of added carbon and chromium are adjusted

so as to reduce non-solute carbides while the matrix

composition are maintained to be that of SKD11 as much

as possible, and (2) a cold die steel referred to 8%Cr

SKD (see JP-A-01-011945) which has improved secondary

20   hardening capability, in which an amount of non-solute

carbides are reduced and an amount of molybdenum is

increased while the matrix composition are maintained

to be that of SKD11 as much as possible.

The above described techniques are effective to improve characteristics required for a cold die steel. However, these techniques have problems to
5 cause a large dimensional change in a tempering step. Specifically, a great dilatation in a secondary hardening region in tempering leads to increase working steps after heat treatment.

The dilatational change of dimension in
10 tempering is caused by a release of a residual stress formed in a previous quenching step (by decomposition of retained austenite), and is promoted by precipitation of temper carbides formed by molybdenum and the like which are conventionally added expecting
15 for secondary hardening. In addition, if the retained austenite is restrained by non-solute primary carbides which have been formed in casting and originally existed, the decomposition thereof in the tempering step is suppressed. However, it is preferable to
20 reduce the primary carbides because they are a factor of degrading machinability, and so the reduction thereof promotes the decomposition of the retained austenite and the dimensional change.

SUMMARY OF THE INVENTION

25   In recent years, in processing industries of a die assembly, the number of working steps before heat treatment is sharply decreased by development in a

processing technique, but the number of working and adjusting steps after heat treatment is not so much changed. Thus, improvements in steps after heat treatment become an urgent matter in particular.

5 Accordingly, the present invention is to provide a cold die steel particularly suitable for a tool material, in which dimensional change is suppressed in quenching and tempering, so that the working and adjusting steps after heat treatment can be reduced which has increased

10 the number of die-manufacturing steps.

First, the present inventors searched for techniques of canceling the dimensional change adversely to suppress the dimensional change which has been difficult to sufficiently suppress, under the

15 condition that the target steel maintains all characteristics required for a cold die steel in tempering. Furthermore, they studied in detail the structural change of a matrix during tempering, and discovered that temper carbides themselves do not

20 contribute to secondary hardening so much. Thus, they have found new means for suppressing the dimensional change and also increasing hardness, and could obtain a cold die steel having other characteristics sufficiently as well.

25 Thus, the present invention provides a cold die steel having a chemical composition described below and excellent characteristics of suppressing the dimensional change.

The cold die steel includes, by mass%, 0.7% or more and less than 1.6% of carbon (C), 0.5 to 3.0% of silicon (Si), 0.1 to 3.0% of manganese (Mn), less than 0.05% including 0% of phosphor (P), 0.01 to 0.12%

5 of sulfur (S), 7.0 to 13.0% of chromium (Cr), one or two elements selected from the group consisting of molybdenum (Mo) and tungsten (W) amounts of which satisfy the formula: (Mo + (W/2)) = 0.5 to 1.7%, less than 0.7% including 0% of vanadium (V), 0.3 to 1.5% of

10 nickel (Ni), 0.1 to 1.0% of cupper(Cu), and 0.1 to 0.7% of aluminum (Al).

The cold die steel preferably satisfies the formula by mass%: Ni/Al = 1 to 3.7%. Furthermore, the cold die steel preferably satisfies the relational

15 formulas by mass%: (Cr - 4.2 × C) = 5% or less; and (Cr - 6.3 × C) = 1.4% or more. In addition, the cold die steel preferably includes 0.3% or less of columbium (Nb).

Important features of the present invention

20 are to suppress the dimensional change by offsetting it, which has been difficult to be basically suppressed, while the characteristics required of a cold die steel are maintained. Although the above described temper carbides have been used for secondary

25 hardening in spite of being the factor of promoting the dilatational change of dimension in tempering, the inventors discovered that the secondary hardening capability thereof are small through a detailed study

of the hardening behavior of the cold work die steel
during heat treatment as described above. The present
inventors have found means for compensating the
shortage of the secondary hardening capability while
5 suppressing the dimensional change. According to the
compensation means, the excellent characteristics of
suppressing the dimensional change and having high
hardness can be achieved without lowering necessary
characteristics including machinability and abrasion
10 resistance.

A principle of the present invention is to
provide a cold die steel excellent in characteristics
of suppressing the dimensional change and having high
hardness, which is based on a chemical composition in
15 which the primary carbides are reduced and the
dimensional change is suppressed in an extent of
satisfying the characteristics, and to which adequate
amounts of nickel and aluminum are added , and besides
an adequate amount of cupper is added corresponding to
20 the amounts of nickel and aluminum.

In the present invention, nickel and aluminum
form intermetallic compounds precipitating in a
secondary hardening region when the above described
tool steel is tempered (aged), which cause a
25 contractional change of dimension, and thereby can
cancel the above described dilatation due to the
decomposition of the retained austenite. It is
important for the above described setoff effect to

precipitate the Ni-Al intermetallic compounds at the
secondary hardening temperature of the tool steel, and
the amount of cupper having the effect therefor should
be appropriately controlled.

5   Furthermore, with the use of a transmission
electron microscope, the present inventors studied in
detail the structural change of the matrix in heat
treatment for high-temperature tempering in which the
retained austenite decomposes and temper carbides

10 precipitate, which particularly causes many problems of
the dilatational change of dimension. As a result, the
inventors confirmed that temper carbides which promote
the dimensional change greatly contribute to improve
abrasion resistance, but can not confirm that fine

15 carbides are precipitated, although they have been
conventionally considered to particularly contribute to
secondary hardening. They found that the degree of
secondary hardening is greatly affected by factors in
the matrix.

20   Ni-Al intermetallic compounds adopted in the
present invention have a secondary hardening effect as
a precipitation strengthening element, thereby further
compensates the secondary hardening in addition to the
above described setoff effect of the dimensional

25 change. Thus, excellent resistance to the dimensional
change and high hardness characteristics can be
achieved without lowering other necessary
characteristics such as machinability and abrasion

resistance.

The precipitation strengthening method with intermetallic compounds has been conventionally often applied to a maraging steel, but has not been used in the field of a tool steel including 0.2 mass% or more of carbon, and particularly in the field of a cold die steel which relates to the present invention. In addition to the characteristics of canceling a dimensional change, the present inventors knew that temper carbides do not actually have such a high secondary hardening effect on the tool steel in itself as has been considered, and consequently noticed to use such an intermetallic compound. Because nickel and aluminum act individually to lower the required properties of the tool steel, an appropriate composition and alloy design for the tool steel are necessary in consideration of the mutual interaction of them with cupper.

Next, a dimensional change generated in quenching will be described. The degree of the dimensional change depends on an amount of a solid solute carbon existing in a matrix when it is quenched. In other words, the dimensional change is generated due to the expansion of crystal lattices by the force of a solute carbon in a martensitic structure. In a conventional steel, an alloy composition is totally designed so that the amount of solid-solute carbon can be in the vicinity of 0.6 (mass %) when quenched, which

value is analogous to SKD11. But the cold die steel
according to the present invention is designed to have
such a composition that the amount of solid-solute
carbon is intended to be about 0.53% which is lower
5 than that in the conventional steel.

The design of the composition is achieved by
addition of elements such as cupper, nickel and
aluminum, which decrease the amount of solid-solute
carbon. That is a principle of the design for
10 suppressing dilatation in quenching. A preferable
conditions of achieving such an amount of solid-solute
carbon are, in addition to the basic composition and
the appropriate amount of cupper, nickel and aluminum
to be added which are specified in the present
15 invention, to control amounts of carbon and chromium to
be added in the whole cold die steel so as to satisfy
the formulas: $(Cr - 4.2 \times C) = 5$ or less, and $(Cr - 6.3 \times C) = 1.4$ or more, preferably $(Cr - 6.3 \times C) = 1.7$ or more.

FIG. 1 shows a summarized concept for the
20 above conditions. (*Note: in FIG. 1, reference
character A shows "an effect for suppressing dilatation
due to decrease of an amount of solid-solute carbon";
reference character B shows "that the dimensional
change are setoff due to precipitation strengthening";
25 and reference character C denotes "a secondary
hardening temperature of the steel according to the
present invention.")

The figure shows that the cold die steel

according to the present invention causes larger
secondary hardening than JIS SKD11, but can suppress
the dimensional change more effectively than that. A
principle of the present invention is to simultaneously

5 satisfy the two points of: (1) decreasing the amount of
solid-solute carbon in quenching (see the reference
character A in FIG. 1); and (2) offsetting a volume
change of a matrix in secondary hardening, due to
addition of cupper, nickel and aluminum (see the

10 reference character B in FIG. 1). Regarding the
concept for the item (1), it is most important
industrially to control the amount of solid-solute
carbon to be approximately 0.53% at a general-purpose
quenching temperature of about 1,030°C. Regarding the

15 concept for the item (2), as it is concerned that
adding of cupper and nickel might degrade hot and cold
workabilities, it is important to keep a balance
between the level for preventing the degradation
thereof and that for causing the maximum precipitation

20 strengthening.

The composition of the cold die steel
according to the present invention will be explained
below. In the following description, a notation of %
means mass percent, for indicating a content of each

25 element.

Carbon (C) is an important element which
partly solutes in a matrix to impart strength thereto,
and partly forms carbides to improve wear resistance

and resistance to seizure. A ratio of an amount of
solid-solute carbon to that of carbon in carbides in
the steel is mainly determined by an interaction
between carbon and chromium, so that the carbon content
5 must be simultaneously specified with chromium content
in consideration of the interaction therebetween.
However, in order to obtain a practical cold die steel
which have well-balanced machinability and heat
treatment deformation stability, the amount of carbon
10 is independently in a range of 0.7 to 1.6%, preferably
in a range of 0.9 to 1.3%.

Silicon (Si) is an important element for the
cold die steel according to the present invention.
Although about 0.3% of silicon is normally added as a
15 deoxidizing agent, 0.5% or higher of silicon is added
in the present invention which is higher than usual.
It is important to prevent a softening of the steel
below a tempering temperature of about 490°C, because it
is concerned that quenching hardness of the steel may
20 be lowered due to a design of the composition for
suppressing the dilatation in quenching. However, as
an excessive silicon content causes formation of a
delta ferrite, the upper limit is defined to be 3.0%.
A preferable amount of silicon is in a range of 0.9 to
25 2.0%.

Manganese (Mn) is used for a deoxidizing
agent as well as silicon, and the steel contains at
least 0.1% of manganese. However, as an excessive

manganese content lowers machinability, the upper limit
is defined to be 3.0%. A preferable amount of
manganese is in a range of 0.1 to 1.0%.

Chromium (Cr) is an indispensable element for
5   forming carbides as well as for enhancing
hardenability. A ratio of an amount of solute chromium
with respect to that of chromium in carbides is
determined by interaction between chromium and carbon
as in the case of carbon. Thus, the chromium content
10 must be simultaneously specified with the carbon
content in consideration of the interaction
therebetween. However, in order to obtain a practical
cold die steel which has well-balanced machinability
and heat treatment deformation stability, an amount of
15 chromium is independently in a range of 7.0 to 13.0%,
preferably in a range of 8.0 to 11.0%.

Molybdenum (Mo) and tungsten (W) impart a
similar working-effect to the steel, the level of which
can be specified by (Mo + (W/2)) in consideration of an
20 atomic weight. Molybdenum and tungsten are considered
to play an important role in secondary hardening of a
tool steel, so that large amounts of molybdenum and
tungsten are added to a high-speed tool steel requiring
high hardness, for they are used in small products such
25 as a byte or a drill. In the present invention as
well, molybdenum and tungsten are indispensably added
because they greatly contribute to a matrix condition
for developing secondary hardening. If the content is

less than 0.5% a sufficient effect is not obtained.

But on the other hand, excessive addition is not

preferable for large products such as a cold die

assembly because these elements promote the dimensional

5   change as described above. Accordingly, in the cold

die steel according to the present invention, an amount

of (Mo + (W/2)) is defined to be in a range of 0.5 to

1.7%, preferably in a range of 0.75 to 1.5%.

       Aluminum (Al) is coupled with nickel to form

10   a Ni-Al intermetallic compound such as Ni_3Al or NiAl,

and causes secondary hardening through its

precipitation. A matrix is retracted through the

precipitation reaction, which cancels the dilatation

reaction in the tool steel in secondary hardening. As

15   a result, the dimensional change is suppressed. Thus,

aluminum is an important element in the present

invention. However, the aluminum content of less than

0.1% does not provide a sufficient effect, but on the

other hand, an excessive content exceeding 0.7% causes

20   a remarkable formation of a delta ferrite, so that an

amount of Aluminum is specified to be in a range of 0.1

to 0.7%, preferably in a range of 0.1 to 0.5%, further

preferably in a range of 0.15 to 0.45%.

       Nickel (Ni) is coupled with aluminum to form

25   a Ni-Al intermetallic compound which precipitates as

described above, and simultaneously thereby causes

secondary hardening and the suppression of the

dimensional change. Thus, nickel is an important

element in the present invention. In addition, it is
an useful element for preventing red brittleness of the
cold die steel according to the present invention which
contained cupper as described below. The nickel
5 content of less than 0.3% does not provide a sufficient
effect, but on the other hand, an excessive content
exceeding 1.5% increases a solubility limit of carbon
in iron and lowers the workability in an annealed
state. Thus, an amount of nickel is specified to be in
10 a range of 0.3 to 1.5%, preferably in a range of 0.4 to
1.5%, further preferably in a range of 0.5 to 1.3%.

Furthermore, if amounts of nickel and
aluminum are adjusted so as to satisfy the relationship
of Ni/Al = 1 to 3.7, amounts of nickel and aluminum in
15 the matrix, which do not form an intermetallic
compound, can be adjusted. Thus, the amount of nickel
in the matrix can be reduced particularly after the
intermetallic compound has been precipitated, so that
the steel can keep good machinability after heat
20 treatment (aging). A preferable ratio of nickel to
aluminum is 1.2 to 3.7. A more preferable one is in a
range of 1.3 to 3.7, and a further preferable one is in
a range of 2.5 to 3.5.

As for cupper, a metal phase of cupper starts
25 to precipitate from a temperature of about 480°C or
higher and forms a nucleus of precipitation for an
intermetallic compound, so that it enables the above
described Ni-Al intermetallic compound to precipitate

just at the vicinity of a secondary hardening
temperature of the tool steel, although the compound
originally precipitates at a higher temperature.
Accordingly, it makes the tool steel according to the
5   present invention develop fully the offset effect of
the dimensional change and the secondary hardening
effect due to the precipitation of the Ni-Al
intermetallic compound. However, as a large amount of
cupper causes red brittleness, it is important in the
10   present invention to specify the amount thereof to be
in a range of 0.1 to 1.0%, preferably in a range of 0.2
to 0.8%.

Sulfur (S) is an useful and indispensable
element for the cold die steel according to the present
15   invention, because it improves machinability. However,
as an excessive content lowers toughness, the content
is in a range of 0.01 to 0.12%, preferably 0.03 to
0.09%.

Columbium (Nb) is a preferable element to be
20   contained for the cold work die steel according to the
present invention, because it functions to make
carbides distribute uniformly in a structure and reduce
deformation due to heat treatment. An amount of
columbium is preferably 0.03% or more, but is desirably
25   0.3% or less, because columbium contained in the steel
forms an MX compound and an excessive amount of the
compound impairs machinability.

In addition, the following elements may be

contained in the steel according to the present
invention so far as being controlled in the following
range.

Phosphor (P) is controlled to be less than

5   0.05%, preferably 0.02% or less, because it is an
element which lowers toughness. Vanadium (V) can be
added to improve hardenability, but it lowers
machinability. Thus an amount of vanadium is limited
to be less than 0.7%, preferably 0.5% or less, even

10 though it is added.

The present invention provides a cold die
steel which satisfies the above described conditions
and contains iron (Fe) substantially as the balance.
Characteristics of suppressing a dimensional change and

15 excellent secondary hardening are achieved by the cold
die steel which consists of, for instance, the above
described elements, iron, and other elements of 20% or
less, 10% or less, or 5% or less in total, or which
consist of the above described elements and the balance

20 of iron with unavoidable impurities.

Examples according to the present invention
will be described below with reference to the drawings.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is a view which shows dimensional

25 changes and hardness due to tempering for cold die
steels to explain an effect of the present invention;

FIG. 2 is a view showing dimensional changes

of cold die steels due to heat treatment;

FIG. 3A is a front view of a test piece used in an example according to the present invention, for measuring a quantity of torsion of cold die steels due

5 to heat treatment;

FIG. 3B is a side view of a test piece used in an example according to the present invention, for measuring a quantity of torsion of cold die steels due to heat treatment; and

10 FIG. 4 is a view showing a quantity of torsion of cold die steels due to heat treatment.

DETAILED DESCRIPTION OF THE INVENTION

Example 1

Samples No. 1 to 6 according to the present

15 invention and comparative examples No. 7 to 9 were melt with a high-frequency induction heating device in the ambient atmosphere, and formed into ingots with a cross section size of 80 × 80 mm , each of which has a composition shown in Table 1 with the balance of iron

20 and unavoidable impurities. Here, the sample No. 7 is a material referred to JIS SKD11, while the sample No. 8 is 8%Cr SKD and the sample No. 9 is 10%Cr SKD.

Table 1

	C	Si	Mn	P	S	Cr	Mo	W	V	Ni	Cu	Al	Nb	Fe	Mo+W/2	Ni/Al	Cr-4.2C	Cr-6.3C
	Composition (mass%)																	
Present Invention No. 1	1.11	1.31	0.58	<0.01	0.06	8.95	1.1	<0.1	0.25	0.78	0.42	0.27	<0.03	Bal.	1.1	2.889	4.288	1.957
" No. 2	1.19	1.49	0.62	<0.01	0.12	9.12	0.8	0.21	0.35	1.02	0.78	0.31	<0.03	Bal.	0.905	3.290	4.122	1.623
" No. 3	0.72	1.51	0.61	<0.01	0.06	7.20	1.0	0.13	0.21	0.81	0.49	0.28	<0.03	Bal.	1.065	2.893	4.176	2.664
" No. 4	1.51	1.52	0.64	<0.01	0.01	12.3	1.25	0.32	<0.1	1.02	0.61	0.29	<0.03	Bal.	1.410	3.517	5.958	2.787
" No. 5	1.18	1.05	0.57	<0.01	0.06	10.4	0.88	0.24	<0.1	0.79	0.54	0.26	<0.03	Bal.	1.000	3.038	5.444	2.966
" No. 6	1.02	1.51	0.56	<0.01	0.07	8.40	0.91	<0.1	<0.1	0.52	0.39	0.35	0.13	Bal.	0.91	1.486	4.116	1.974
Comparative Example No. 7	1.49	0.35	0.38	<0.01	<0.01	12.2	1.04	0.35	0.25	<0.01	<0.01	<0.01	<0.03	Bal.	1.215		5.942	2.813
" No. 8	0.98	1.11	0.41	<0.01	<0.01	7.95	1.98	0.30	0.25	<0.01	<0.01	<0.01	<0.03	Bal.	2.130		3.834	1.776
" No. 9	1.18	0.39	0.42	<0.01	0.06	10.2	1.02	0.25	0.25	<0.01	<0.01	<0.01	<0.03	Bal.	1.145		5.244	2.766

At first, these ingots were hot-worked into a wire material with a cross section size of 15 mm × 15 mm. They were then annealed, and test pieces of 8 mmϕ × 80 mmL were formed, and the longitudinal dimensions

5   thereof were measured. Then, they were quenched at 1,030°C (nitrogen cooling at a pressure of 0.506 MPa), and subsequently subjected to high-temperature tempering twice to be secondary hardened so as to have a hardness around 60 to 63 HRC. The dimensions were

10   measured again at this condition. The sample No. 8 (8%Cr SKD) is secondary hardened at a tempering temperature of about 525°C, and the other samples are secondary hardened at a tempering temperature of about 510°C. All samples of No. 1 to 6 after heat treatment

15   have higher hardness than that of SKD11 (No. 7), which means that those samples have excellent secondary hardening capability.

FIG. 2 shows a dimensional change of each sample due to heat treatment, or, a dimensional change

20   during secondary hardening. The dimensional change during heat treatment was calculated from the measurements on longitudinal dimensions before and after the above described heat treatment, by using the following formula.

25   dimensional change during heat treatment = ((dimension after heat treatment-dimension before heat treatment)/dimension before heat treatment) × 100

The sample No. 8 has the largest dilatation and shows the largest dimensional change. This is because it contains excessive molybdenum. The samples No. 7 and 9 have compositions adequately adjusted to

5   have an amount of molybdenum equivalent of (Mo + (W/2)) being about 1.0%, but still cause the dilatation around 0.05%. In contrast, the samples of No. 1 to 6 containing the appropriate amounts of nickel, cupper and aluminum show the dimensional change due to heat

10   treatment controlled to be 0.01% or less. The result shows that a precipitation reaction of Ni-Al intermetallic compounds in a secondary hardening region offsets the dilatation.

Example 2

15   A test piece having a form shown in FIGS. 3A (front view) and 3B (side view) was produced from the annealed steels. In FIG. 3A, each clearance (gap size) at the positions of arrow (1) (at 2.5 mm from the left), arrow (2) (at 5.0 mm from the left) and arrow

20   (3) (at 7.5 mm from the left) is 0.5 mm. The test pieces were then heat-treated in the same way as in Example 1, and the clearances at the same positions were measured again. A "quantity of torsion" was determined from changes of the clearances based on the

25   following formula;

quantity of torsion (absolute value) =

|(average variation of (1) to (3)) - (the further value

from the above described average value, selected from

values (1) and (3))|.

5   The results of the calculated quantities of

torsion are shown in FIG. 4. The sample No. 7 has the

largest quantity of torsion. This is because the

sample contains a large amount of solid-solute carbon

in the martensite and a large amount of non-solute

10   carbide, and thereby a strong inner stress is generated

by the dilatation of the matrix and the restraint by

the non-solute carbides. The samples No. 8 and 9 have

a large quantity of torsion in spite of containing few

non-solute carbides, but the samples of No. 1 to 6, in

15   which the inner stress of the matrix is offset by the

precipitation of Ni-Al intermetallic compounds,

obviously have small quantities of torsion.

Furthermore, the sample No. 6 containing the

appropriate amount of columbium provides an adequate

20   result that torsion was not measured within the

measurement accuracy of ±0.0001 mm.

The tool steel in the present invention are

not dimensional changed and deformed due to heat

treatment, and makes it possible to reduce/omitted

25   finish working for correction after heat treatment.

Thus, manufacturing cost for the die assembly can be

reduced. The tool steel further make it possible to

shorten a period for manufacturing the die assembly, and to heat treat a die having a more complicated shape, so that the present invention is an industrially extremely useful technology.

5 INDUSTRIAL APPLICABILITY

The cold die steel according to the present invention is preferably used as a tool material for forming components in machines.